European Journal of Geography Volume 7, Number 3:57 - 69, September 2016
©Association of European Geographers

THE CIRCULAR STRUCTURES OF THE REPUBLIC OF ARMENIA BASED ON A DIGITAL ELEVATION MODEL.

Artak PILOYAN
Masaryk University, Faculty of Science, Department of Geography, Czech Republic
https://www.muni.cz/sci
artakpiloyan@mail.muni.cz

Arshavir AVAGYAN
Laboratory of Geoinformatics, Institute of Geological Sciences, National Academy of Sciences, Yerevan, Armenia
http://www.geology.am/en/home
avagyan@geocom.am

Abstract

Through the morphometric analysis of a three-dimensional Digital Elevation Model (DEM) of the Republic of Armenia (RA) at a 1:200000 scale, circular forms of the relief have been discovered by the authors of this article. The largest and the most distinctive ones have forms which have specific features of geomorphological structures and are described herein. Exposure in relief, features of geological and tectonic structure, spatial proximity of ore deposits and possible origin of several circular structures are discussed in the article. A map of spatial distribution of circular structures on the territory of the RA and large scale shaded relief maps of the most typical groups of circular structures and single structures are presented.

Keywords: *Geomorphology, Geomorphometry, Circular Structure, GIS, DEM.*

1. INTRODUCTION

Circular type structures (or ring structures) are typical of the Terrestrial planets. On all the planets other than the Earth, they make up the basic structural pattern of the surface. These are mainly meteorite craters. Their number on the Earth is not so large. This is explained by the fact that because of the formation of strong layers of the atmosphere, only large meteoritic bodies reached the Earth's surface, smaller ones burned in the atmosphere. Moreover, the Earth, unlike the other Terrestrial planets is a "live planet", and both exogenous and endogenous processes of high intensity erase circular structures from the Earth’s surface, even those which are very young from a geological point of view. Nevertheless, quite a large number of them stand out on the Earth's surface through interpretation of satellite and aerial imagery, geomorphostructural and geomorphometric analysis, and in certain cases through a geophysical survey (Abramovic and Turkova, 2005).

Circular structures (CS) of small and medium sizes on the Earth are divided into two major groups by the origin: endogenous and exogenous. Endogenous structures are circular volcano-tectonic structures, the zonal intrusions of the central type, granite-gneiss domes, gneiss folded ovals, tectonic depressions, and calderas etc. Structures of exogenous origin are presented by impact craters, sinkholes and aeolian landforms etc. (Abramovic and Turkova, 2005). Eppelbaum, L. V. gives a detailed classification of circular structures by the origin classified as terrestrial, extraterrestrial and archaeological. The terrestrial group includes magmatic, tectonic, metamorphic and erosion origin. The extraterrestrial type of CS includes impact calderas (Eppelbaum, 2007).

Publications on the topic of CS mainly refer to the period of 1960-1980 when first there was wide access to aerospace photos taken of the Earth's surface. The interpretation of the photos widely developed within these years and helped to state the fact of wide distribution of CS on the Earth's surface. According to the interpretations of aerospace photos, small-scale maps of CS were created and patterns of their spatial distribution were established. Through combined concomitant geological fieldworks expressions of them in the geological structure were found, as well as arguments for conclusions on the origin of a part of them.

Most publications on this topic are diverse from the point of details, the scope of territory observed and applied methods of investigation.

A group of authors (Kats et al., 1989) published a detailed review on circular structures where examples of their geological (metamorphic, magmatic, tectonic) and cosmogenic origin were shown. As stated by the authors, CS have a varied and complicated structure. Drainage network within their limits often has a radial structure (diverging from the center in case of a convex form of the relief structure and converging – in the case of a concave form). They are characterized by a central core and complicated by a system of radial, concentric tectonic faults, segmental or continuously expressed in the relief. They also described circular structures the central part of which occupies the tectonic uplift or depression, while the periphery is limited by folded ridges and by intrusive massifs.

An example of detailed CS analysis is the investigation of mega morphostructures in East Asia (Kulakov et al, 2000). The authors discovered series of gigantic ring-morphostructures (RM) along the eastern margin of the Asian continent with the diameter of from 1 - 2 to 3 - 4 thousand kilometers. One of them is the Amur mega-RM which is more than 2500 km in diameter and covers the whole basin of the Amur River as well as series of small basins connected with the Seas of Okhotsk and Japan. A system of radial-concentric deep "framework" faults control the main features of the geomorphological and tectonic structure of the Amur RM. The authors considered that this morphostructure and other gigantic RM created in Precambrian have a spatial-genetic connection with the well investigated Amur-Songhua-Huanghe lineament (ASHL) and developed simultaneously with it.

According to the interpretation of aerospace photos and the results of morphostructural analysis of the relief in the territory of the Eastern Sayan, more than 500 ring structures with the diameter of 1-160 km are counted (Abramovic and Turkova, 2005). Using the details of large-scale geological maps the authors were able to date the age and describe the geological nature of most of the discovered structures.

In the most part of the investigation, single CS were observed. For instance, circular structures with the diameter of 2-5 km in sedimentary formations of Saudi Arabia are described, presumably referring to the impact type (Stewart, 2015). The given author mentioned a group of about 100 CS the genesis of which is not defined yet. A circular structure of impact origin was discovered in Senegal using the Synthetic Aperture Radar (SAR) (Wade et al., 2001). Another single circular structure was discovered and described in southeastern Libya (Ghoneim, 2009).

In different years circular geomorphological structures also were identified in the RA and in its surroundings, based on the interpretation of aerial and satellite images (Arakelyan, 1978; Lukina et al., 1983; Ostroumova and Golynko 1983; Bondyrev, 2003). According to the results of recent scientific research, many regularly arranged relative to each other linear, circular and helical elements observed in satellite images correspond to geological structures and have a tectonic origin and frequently occur during the evolution of the Earth's crust (Arakelyan, 1978). Several of them, according to remote sensing data and concomitant geological fieldwork, were assessed as morphostructures of tectonic origin. At the same time, the research of Alaverdi volcano-tectonic structure discovered concentric structures of different ages–calderas, the outer part of which is marked with arc-shaped faults (Ostroumova and Golynko, 1983). In the following years, investigators paid more attention to the investigation of lineaments in the territory of RA. Single circular structures were pointed out as well as, however, there has not been enough regular investigation on the identification and mapping, and currently only separate handwritten works and rare publications contain information on this topic.

The given article presents the results of the investigation of circular structures. As a result of the geomorphometric analysis, the authors of this article have identified a number of circular features on the territory of the RA. The investigation aimed at identifying definite circular structures, mapping them, describing their features, highlighting peculiarities of their spatial distribution, systemizing on specified grounds and origin.

2. STUDY AREA

The Republic of Armenia is a typical mountainous country, the surface of which is a complicated combination of blocked, fold-blocked and volcanic mountains, alluvial plains and high-mountainous volcanic plateaus, canyon-shaped river valleys and lake hollows (Geol. of Arm. SSR, 1962).

A typical characteristic of the hypsometry of the territory of the RAa is a sequence of four major geomorphological zones (from north to south) which are different in origin and altitude statistics: Those zones are 1) The Zone of Northern Fold-block Ranges and Intermountain Valleys, 2) The Volcanic Highland, 3) The Zone of Southern Fold-block Ranges and Intermountain Valleys and 4) Middle Araks Depression (Figure 1).

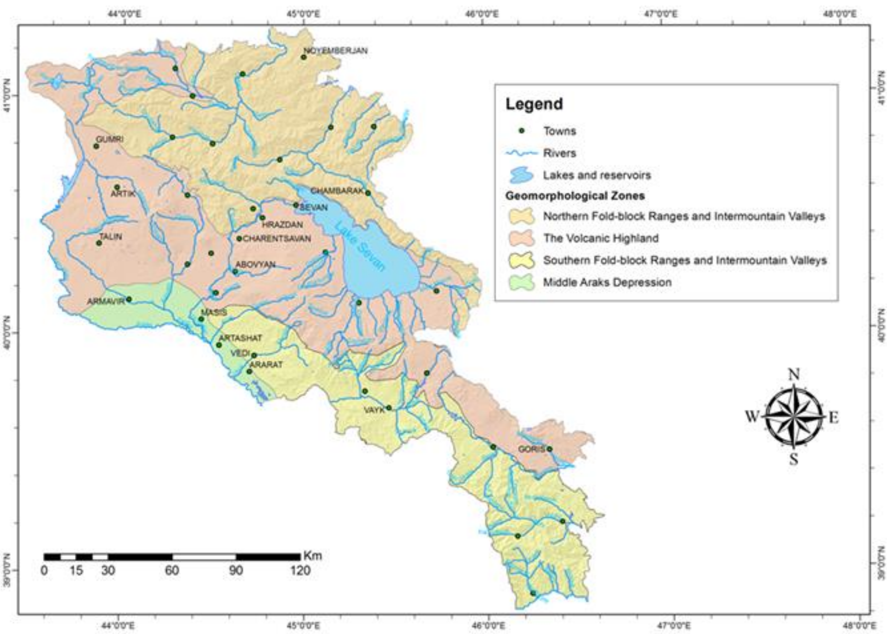

Figure 1. Map of the Geomorphological Zones of the Republic of Armenia

Based on the data of the hypsometric curve, we can say that the territory of the RA is a medium-altitude mountainous country dominated by absolute altitudes of 1300-2500 m

(Figure 2). The visual analysis of the hypsometric curve shows that 10.49% of the territory of the RA is situated at altitudes up to 1000 m, and almost half (47.84%) - from 1000 to 2000 m. Only 14.41% of the total territory are the areas situated above 2500 m. The highest point in the territory of the RA is the northern peak of mount Aragats – 4090 m; and no point is below 390 m: the lowest points are in the valley of the Araks River at the state border with Iran. The average elevation of the territory is 1853.32 m (Avagyan,Yeritsian and Piloyan, 2010).

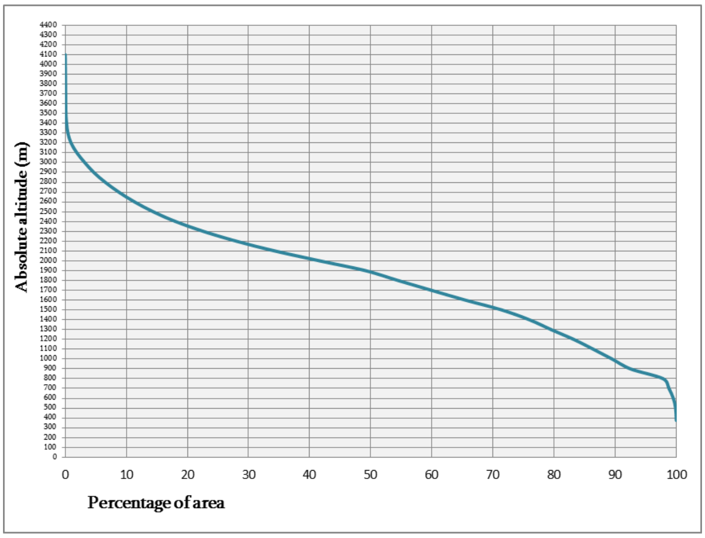

Figure 2. Percentage hypsometric curve of the territory of the Republic of Armenia.

It is worth mentioning that hypsometry of fold-block mountains usually develops by neotectonic movements which are differentiated in the RA (Zohrabyan, 1979). Within the individual blocks of the Earth's crust, they are expressed in different degrees of intensity and by different amplitudes. This phenomenon creates various elevation levels of relief for young mountains. During the formation of hypsometry of neovolcanic relief, along with the neotectonic movements, lavas and the tuff cover are also affecting. However, in the territory of the RA, their power is low (maximum a few hundred meters). For this reason, the main hypsometric levels in such kind of relief basically repeat the hypsometry of the relief which is below the lava cover (Zohrabyan, 1979).

The relief of the territory of the RA on most of its territory is a succession of meso forms of relief. The Zones of Northern and Southern Fold-block Ranges and Intermountain Valleys and the main part of The Volcanic Highland are alternation valleys, ridges, crests, summits, passes, channels, pits, hollows and other geomorphological middle-level forms.

3. GEOMORPHOMETRIC APPROACH FOR IDENTIFICATION OF CIRCULAR STRUCTURES

The review of the published literature shows that circular structures in most cases were identified by the interpretation of satellite and aerial imagery and geomorphostructural analysis. For identifying and mapping CS the authors used geomorphometric maps - shaded relief, slope, aspect and horizontal curvature of the relief. Methods of geomorphometry can be used to analyze processes and phenomena in geomorphology, topography, landform identification etc. (Bates et al., 1998; Butler, 2001; Mokaram and Sathyamoorthy, 2015). Circular forms of relief are found on all types of maps, but usually, they are well identified on the color map of slope and aspect. Shary P. A. shows an example of delineation of CS in the Crimea on an aspect map (Shary et al., 2002). Such maps are effective for solving this problem because the intensity of the colors on the map indicates the gradual horizontal change of the slope orientation that comprises the circular structures. The structure borders are defined by the line of terrain fold in a vertical plane that physically coincides with river beds or watersheds.

The most common method for calculating the aspect for the raster models (Digital Elevation Models) is based on the calculation of the first derivative of Z '(X, Y), where Z is the absolute height, X and Y are the geographical coordinates (Borrough, 1998). Aspect at any point of DEM is calculated using the neighboring cells in the 3x3 window (Kernel method). A moving 3 x 3 window visits each cell in the input raster, and for each cell in the center of the window, an aspect value is calculated using an algorithm that incorporates the values of the cell's eight neighbors. As shown in Figure 3 the cells are identified as letters Z_1 to Z_9, with Z_5 representing the cell for which the aspect is being calculated.

Z_1	Z_2	Z_3
Z_4	Z_5	Z_6
Z_7	Z_8	Z_9

Figure 3. Surface window model.

The rate of change in the X and Y direction for cell Z_5 are calculated with the following algorithms (Horn, 1981; Borrough, 1998):

$$\left(\frac{dZ}{dX}\right)=\left(\frac{((Z_3+2Z_6+Z_9)-(Z_1+2Z_4+Z_7))}{8}\right); \quad \left(\frac{dZ}{dY}\right)=\left(\frac{((Z_7+2Z_8+Z_9)-(Z_1+2Z_2+Z_3))}{8}\right).$$

Taking the rate of change in both the X and Y direction for cell Z_5, aspect is calculated using:

$$aspect = 57.29578 \times \arctan 2\left(\left(\frac{dZ}{dY}\right)-\left(\frac{dZ}{dX}\right)\right).$$

In order to justify the fact that the discovered forms of relief are circular structures, the geological features were analyzed and described. Many researchers point out the spatial relationship of mineral deposits with circular structures. Particularly Kats, Ya. G. and his colleagues consider that at least 70-75% of all known deposits in the world are associated with circular structures (Kats et al., 1989). Spatial proximity of mineralization to CS is presented in this article.

It is worth mentioning that different types of CS are differently expressed in the relief and in the geological structure. In this paper, we do not consider CS with a diameter greater than 50 km. The problem of the origin of CS remains disputable. By increasing the diameter of CS, the accuracy of the determination decreases and from a certain size (150-270 km), these structures become difficult for genetic interpretation (Bondyrev, 1991).

Origin of simple circular forms of terrain is more evident on the plan curvature map, formed by Pliocene – Quaternary (Holocene) non-eroded volcanic structures (Figure 4).

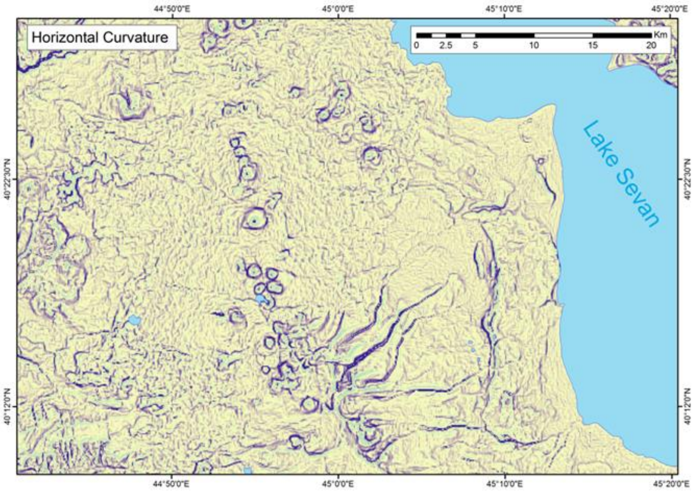

Figure 4. Volcanogenic CS on the horizontal curvature map.

Volcanologists in the RA describe them as large fissure – linear strato-volcanoes and relatively small areal-monogenetic volcanic cones (Jrbashyan et al., 2012). It is common knowledge that circular, segmental, and radial fissures are related to formation of large volcanoes.

4. RESULTS

In the territory of RA more than 50 CS (Figure 5) are quite clearly seen, the diameter of which varies from 3 to 45 km. They are located both in the Northern and Southern fault-block mountain regions, and on the Volcanic Plateau.

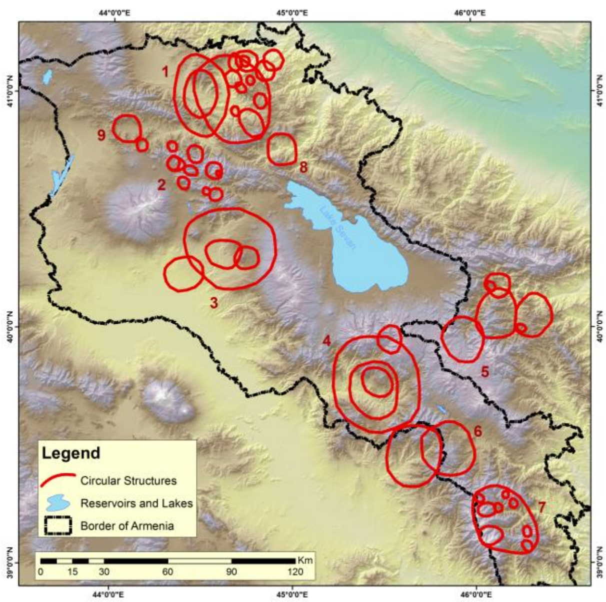

Figure 5. A three-dimensional relief map of the Republic of Armenia (scale of original 1: 200000). CS groups: 1. Gugark-Virk, 2. Pambak-Tsakhkunyatsk, 3. Hrazdan-Geghama, 4.Vayk, 5. Kashatagh, 6. North Zangezur, 7. Meghri-Bargushat. Single CS: 8. Middle Aghstev, 9.Shirak-Pambak

In the Northern and Southern fault-block mountain regions CS are located in six basic groups and are called by the geographic location: Gugark-Virk, Pambak-Tsakhkunyats, Vayk, Kashatagh, North Zangezur, Meghri-Bargushat, two single CS – Shirak-Pambak and Middle Aghstev are also identified. By age, they are divided into the Precambrian, Lower

Paleozoic, Upper Paleozoic-Mesozoic, and Lower Cenozoic. Among the geological-morphological types there are highlighted granite-gneiss domes, volcano-tectonic uplifts, intrusive bodies, tectonic depressions (Table 1). The form, structure, size and spatial relation with ore deposits of the selected structures, according to the numbering on the map of the RA (Figure 5) are described below.

Table 1. Classification of circular structures (CS) in the RA

CS number according to Figure 5	Factor of classification		
	Age	**Geological-morphological structure**	**Spatial distribution**
1	Upper Mezosic-Canozoic	Volcano-tectonic dome uplift, Intrusive bodies	Dominant large structure with small satellites
2	Precambrian - Lower Paleozoic	Granite-gneiss dome, covered by volcanogen sediments	Group distribution
3	Upper Mezosic-Canozoic	Not defined	Dominant large structure with small satellites
4	Upper Mezosic-Canozoic	Volcano-tectonic dome uplift	The spiral distribution
5	Not defined	Not defined	Intersecting distribution
6	Upper Mezosic-Canozoic	Horst-anticline uplift	Intersecting distribution
7	Upper Paleozoic-Mesozoic	Volcano-tectonic dome uplift, Intrusive bodies	Dominant large structure with small satellites
8	Lower Canozoic	Tectonic depression	Single structure
9	Upper Mezosic-Canozoic	Tectonic depression	Single structure

1. The Gugark-Virk CS group consists of two large structures, with the diameter of 45 and 20 km as well as more than 6 CS with smaller sizes (with the diameter from 4 to 15 km). Several other CS intersect with the main structure of the Gugark-Virk group from the north-east (Figure 6).

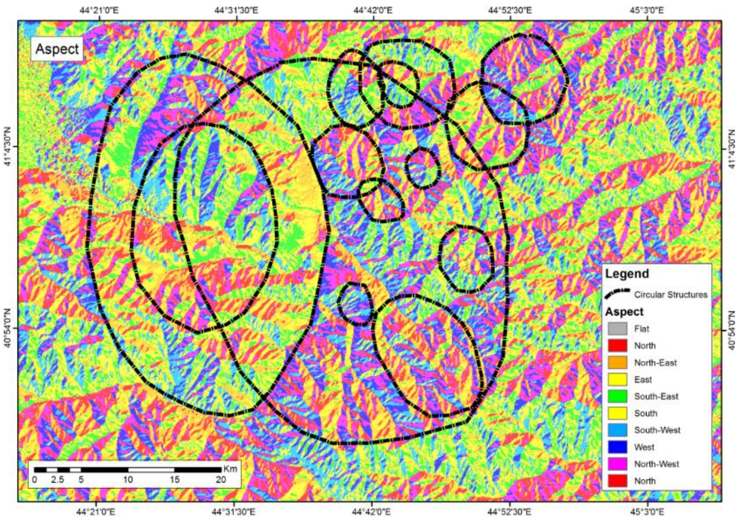

Figure 6. The Gugark-Virk CS group on aspect map

The main structure of the Gugark-Virk CS group is dome uplift, folded Eocene volcanic and sedimentary rocks – diabase porphyries, quartz porphyries and limestone, and Upper Cretaceous and Eocene intrusive rocks – gabbro-porphyries and gabbro-diorites. The Gugark-Virk CS forms the following geomorphological units: from the south and south-east – the Gougark Mountains, from the north and north-east – Lalvar and Ledzhan missives of the Virahayots ridge and from west – the Eastern Bazum ridge. This group of CS is located in a zone between two ancient (Permian) deep faults of north-east trending. Through the center of the CS the young tectonic fault (Neogen-Quaternary) of north-west trending passes (National Atlas RA, 2007). Within this group of CS industrial deposits of Alaverdi, Shamlugh (Cu), Teghut (Cu, Mo), Mghart (Au), Akhtala (polymetallic) are localized.

2. In the Pambak-Tsakhkunyats group, there are ten CS (Figure 7) with the diameter of 3 km to 8 km.

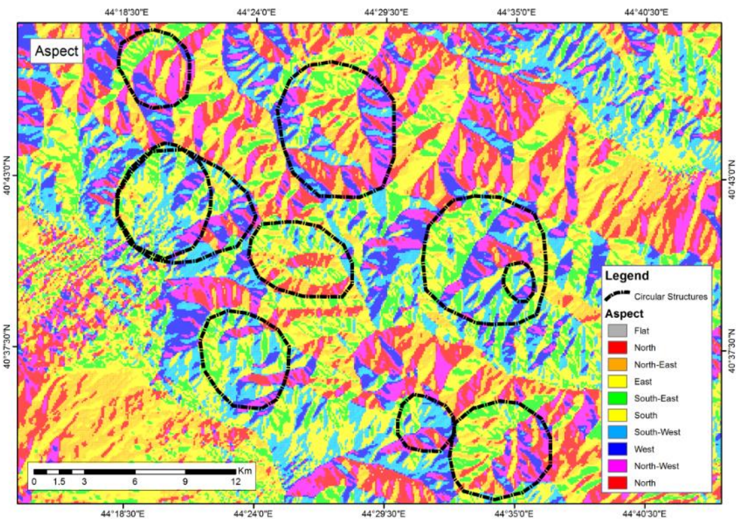

Figure 7. The Pambak-Tsakhkunyats CS group on aspect map

The area is composed of Precambrian - Lower Paleozoic metamorphic and crystalline rocks (gneiss, schist, marble, and migmatites) that are intruded by basic and acid intrusions. These formations are covered by Upper Cretaceous and Paleogene sediments and Miocene-Pliocene lavas and tuff breccias (Gabrielyan, 1959; Aslanyan, 1958). The horst uplift of Arzakan crystalline massif is located at the base of the Pambak-Tsakhkunyats CS group which forms an anticline fold and is bounded by the major faults on the north-east, south-west and south-east. The Pambak-Tsakhkunyats CS group tends Ankavan (Cu, Mo), Gyuladara (Fe), Perevalnoe (Au), Tukh-Manuk (Au, Ag), Tezhsar (Al) deposits.

3. The Hrazdan-Geghama CS group is situated in the central part of the RA. It consists of one large circular structure (47 km), two smaller structures in the center and one intersecting structure in the south-west part of the group. This group is formed by the central and northern part of the Geghama highlands from the east, the Voghjaberd ridge from the south and the Kotayk-Hrazdan volcanic plateau from the west and southern part of the Tsakhkunyats ridge from the north. The geological-morphological structure of this group is not clearly defined. Most probably the core of the Hrazdan-Geghama CS group is the eastern wing of the Geghama anticline. The base of the given structure are the Upper Pliocene dolerite lavas, covered by the young Quaternary lavas.

4. There are three CS in the Vayk group, the largest of which has a diameter of 41 km. The other two smaller CS - 14 km and 24 km in diameter are located concentrically within the first. This group includes the eastern segment of the Vayk ridge and the south-western part of the Vardenis Highlands. In the base of this group from the north lies the south wing of the Vardenis domed uplift, covered by Neogene and Pleistocene lavas, and from the south lies the north wing of the Urts - Ayotsdzor anticlinoria, which is composed of Upper Paleozoic, Cretaceous and Eocene limestone, marl, sandstone and volcanic-sedimentary strata (Geol. of Arm. SSR, 1962). The central part of the group is covered by Quaternary basalts and basaltic andesites. Martiros (Mn), Kaputsar (Au), Kakavasar (Au, Ag), Karmrashen (Mn), Gazma (Au), Azatek (Au, Ag) deposits are confined to the Vayk CS group.

5. The Kashatagh group consists of three large and several smaller CS which are extending from east to west like a chain. The contours of the CS are formed of ridges of Mrav and Artsakh mountains. In this node the largest diameter of CS is 19 km, the smallest one is 4 km. Only a small part of the Kashatagh group is in the territory of the RA.

6. The North Zangezur group is located to the south of the Vayk CS. There are two structures with a diameter of 22 km and 25 km. These are Nakhichevan (almost entirely located outside the RA) and the North Zangezur CS. The North Zangezur CS has a fault-block structure and represents horst-anticline uplift, composed by Eocene and Pliocene rocks. There are also occasional outputs of the Quaternary and Pliocene lacustrine and fluvial sedimentary formations. The East CS of the group intersects with the old deep fault. The gold - polymetallic deposits of Marjan (Au, Ag) and Mazmazak (Pb, Zn, Au, Ag) are associated with the North Zangezur CS group.

7. The Meghri-Bargushat CS group with the diameter of 24 km includes the following morphological units: the Bargushat ridge – in the north, the middle part of Zangezur ridge – in the west and the north ridges of the Meghri ridge – in the south. The Meghri-Bargushat CS is composed of sedimentary and volcanic rocks of the Paleozoic, Mesozoic and Paleogene, among which small intrusive bodies are occasionally seen. From the north of the CS, a deep fault passes. With the Meghri-Bargushat CS are associated the Kajaran (Cu, Mo), Pkhrut, (Au, Ag, Pb, Zn) Ankasar (Mo, Cu) deposits (Figure 8).

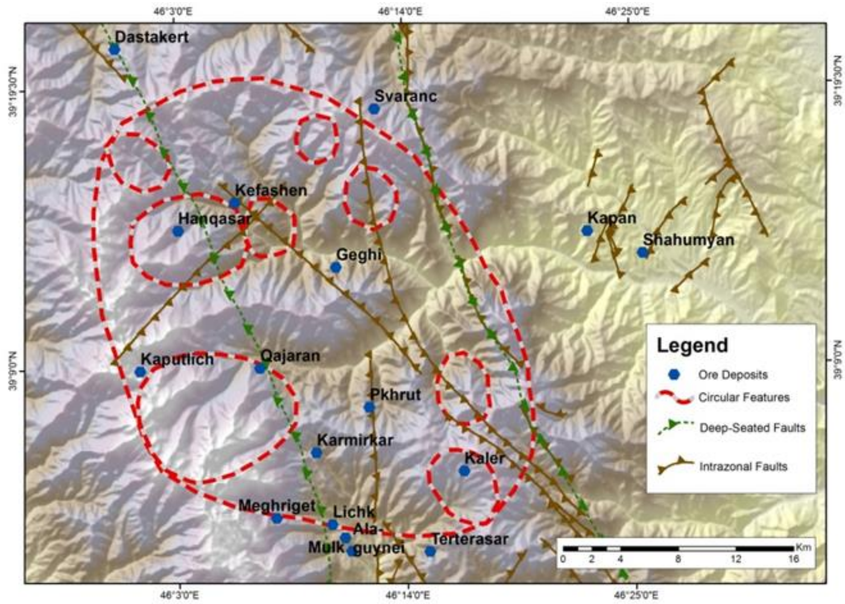

Figure 8. The spatial relationship of ore deposits with the Meghri-Bargushat CS group

8. The Middle Agstev CS has a small diameter of about 12 km. It is clearly expressed in the relief and well reflects the specific structure of the drainage system. The central part of this structure coincides with the Dilijan depression and the edges of its frame with the Halab ridge in the north and with the Miapor ridge from the south. Most of the CS area is covered by volcanic rocks - sandstones, clays, tuffs, basalt flows of the Middle Eocene. In the north of the CS marine sedimentary and volcanogenic-sedimentary formations of mid-Jurassic age are a common sight.

9. The Shirak-Pambak structure is located in the upper valley of the river Pambak. From the north, it is limited by the southern slope of the small Shirak ridge, from the south by the north slope of the Pambak ridge. From the west, it is closed by the meridional Dzhadzhur low ridge, which is the extreme north-western spur of the Pambak ridge. The structure in the periphery is composed of sedimentary and volcano-sedimentary rocks of the Upper Cretaceous, Paleocene and Eocene, and in the center, it is composed of the high thicknesses alluvial-lacustrine sediments of the Pliocene. Tectonically the Shirak-Pambak structure is a depression with 13-15 km long and 12 km wide which somewhat elongated in the latitudinal direction.

5. CONCLUSIONS

CS on the Earth’s surface have been familiar to scientists since a long time ago, yet intensive studies of them and publication of the results were realized in the years 1970-1990 connected with the appearance of the opportunity of using data of remote sensing. The development of the methods of geomorphometric analysis gives additional opportunities for direct identification of the form and the structure of the Earth’s surface as a property of a physical body. The geomorphometric analysis which uses DEM to study CS is promising also for the reason that it allows a quantitative description and characterization of shapes and structures of relief.

Based on satellite and aerial imagery interpretation some single CS were identified in the territory of the RA and also it was suggested that many regularly located to each other linear, circular and helical shaped elements which were observed, correspond to geological structures and have tectonic origin and frequently occur during the evolution of the Earth's crust. It is worth mentioning that targeted research in the given direction did not take place later on in the RA.

The analyses of geomorphometric maps showed that the circular forms of the relief are not unique objects, but commonly shown results of the crust-forming processes. The features of the CS found in the RA correspond to the structure description given in the published literature. One is that the central part of the CS is often tectonic uplift or depression, but it is limited by the periphery of folded ridges or intrusive missives. Radial linear structures are clearly distinguished on the map of the aspect. A concentric and chained-location, as well as a mutual intersection of CS was found, not previously described in literature.

The spatial relationship was revealed between endogenous hydrothermal mineralization and CS. The connection is expressed in the fact that within the boundaries of CS there are large industrial ore deposits of common formational types: Cu-Mo, Cu-pyrite, Au-polymetallic and others. The revealed relationship indicates the endogenous origin of CS.

Evidence was found that CS most probably are controlled by tectonic faults. In particular, known ancient deep faults of north-east trending in the territory of the RA, bound the Gugark –Virk group of CS from the north and the south, and other CS – from the north.

Accordingly, the given facts help us conclude that CS are an essential element of the geomorphological and geological structure of the territory of the RA.

ACKNOWLEDGEMENTS

This publication is based on research that was financially supported by the Institute of Geological Sciences (IGS), National Academy of Sciences of the Republic of Armenia. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of these organization. The authors gratefully acknowledge to the staff of the Geoinformatics laboratory of IGS, who have developed Digital Elevation Model.

REFERENCES

Abramovic, G.Ya., Turkova I.N. 2005. Ring Structures of the Eastern Sayans. In: *Geology and mineral resources of East Siberia*, ed. A.I. Sizykh, 105-113. Irkutsk, Irkustsk Uni. Press.

Arakelyan, R.A. 1978. Some regularities of distribution and relationship of rectilinear and curved forms, reflected in satellite images. Proceedings of the Universities. *Series of geology and exploration*: 10: 178-180

Aslanyan, A.T. 1958. Regional Geology of Armenia. Yerevan: Aypetrat.

Avagyan, A.A., Piloyan A.S., Yeritsian, H.H. 2010. On Elevation Characteristics and Methodology of its Calculations of Terrain of the Republic of Armenia Based on 1:200000 Scale Digital Elevation Models. Proceedings of the National Academy of Sciences of Armenia. *Earth Science Series*: 63 (3): 48-58.

Bates, P.D., Anderson, M.G., Horrit, M. 1998. Terrain information in geomorphological models: stability, resolution and sensitivity. In: *Landform Monitoring, Modelling and Analysis*, ed. S. Lane, K. Richards, J. Chandler, 279–309. Chichester: Wiley.

Bondyrev, I.V. 1991. *Aerospace research and the problem of ring structures*. Tbilisi: Academy of Sciences Press.

Bondyrev, I.V. 2003. Ring structures of Georgia. *Geotectonics*: 2: 98-108.

Burrough, P. 1998. *Principles of Geographic Information Systems*. New York: Oxford University Press.

Butler, D., 2001. Geomorphic process-disturbance corridors: a variation on a principle of landscape ecology. *Progress in Physical Geography*: 25 (2): 237–248.

Eppelbaum, L.V. 2007. Localization of Ring Structures in Earth's Environments. Journal of the Archaeological Society of the Slovakian Academy of Sciences, Spec. Issue: Arch. Prosp. XLI: 145-148

Gabrielyan, A.A. 1959. Major issues of Armenia tectonics. Yerevan: Academy of Sciences Press.

Geology of the Armenian SSR. 1962. Geology of the Armenian SSR. V. I, Geomorphology. Yerevan: Academy of Sciences Press.

Ghoneim, E.M. 2009. Ibn-Batutah: A possible simple impact structure in southeastern Libya, a remote sensing study. *Geomorphology*: 103: 341–350.

Horn B. 1981. Hill Shading and the Reflectance Map. Proceedings of the IEEE: Vol. 69: 14 - 47.

Jrbashyan, R.T., Ghukasyan, Yu.G., Karapetyan, S.H., Mnatsakanyan, A.Kh., Navasardyan, G.Kh. Gevorgyan, H.R. 2012. Types of volcanic eruptions and forms of manifestation of the late – collision on – land volcanism in Armenia. Proceedings of the National Academy of Sciences of Armenia. *Earth Science Series*: 65 (3): 3-20.

Kats, Ya.G., Poletaev, A.I., Sulidi-Kondratiev, E.D. 1989. *Ring structures of the Earth: Myth or reality*. Moscow: Nauka.

Kulakov, A.P., Qiu, S.W., Miasnikov, E.A., Wang X.K., Tashchi S.M., Zhao H.Ch., Song, Ch.Ch. 2000. Ring-morphostructures of the Amur-Songhua-Huanghe lineament (eastern margin of Asia). *Chinese Geographical Science*: 10 (4): 348–355.

Lukina, N.V., Karakhanyan, A.S., Senin, B.V. 1983. Linear and circular structures of Crimea-Caucasus region. *Space data in geology*: 15 (2): 195-207.

Mokaram, M., Sathyamoorthy, D. 2015. Morphometric analysis of hydrological behavior of North Fars watershed, Iran. *European Journal of Geography*: 6 (4): 88-106.

Ostroumova, A.S., Golynko, I.A. 1983. The comprehensive study of volcanic formations (in the Alaverdi ore node example). Principles and methods for assessing ore geological formations. *Magmatic formations*: 21 (3): 236-248.

Shary, P.A., Sharaya, L.S., Mitusov, A.V. 2002 Fundamental quantitative methods of land surface analysis. *Geoderma*: 107 (1-2): 1-32.

Stewart, S.A. 2015. Circular geological structures outcropping in the sedimentary basins of Saudi Arabia. *Journal of Asian Earth Sciences*: 106: 95–118

Volchanskaya, I.K., Jrbashyan, R.T., Meliksetyan, B.M., Sarkisyan, O.A., Favorskaya, M.A. 1971. The block structure of the North-West of Armenia and the particularities of the magmatic and ore manifestations's placement. *Soviet geology*: 8: 15-27.

Volchanskaya, I.K, Sarkisian, O.A. 1973. The block structure of the territory of the Armenian SSR and the neighbor regions of the Lesser Caucasus. Proceedings of the National Academy of Sciences of Armenia. *Earth Science Series*: 23 (4): 6-9.

Wade, S., Barbieri, M., Lichtenegger, J. 2001. The Velingara Circular Structure– A meteorite impact crater? *ESA Bulletin*: 106: 135-139

Zohrabyan, L.N. 1979. Orography of the Armenian highland (experiment in orographical analysis of morphostructure).Yerevan: Arm. SSR NAS Press.